by a 6.2 mm nozzle, and 12° included angle expansion section followed a 20.0 mm I.D., 50.0 cm cool down section. The cooled mixture of titanium powder and gas was passed through two sonic cyclone particle separators to collect the ultrafine powder. Hydrogen chloride vapor was condensed out in a liquid nitrogen cooled cold trap to prevent damage to the mechanical vacuum pump down stream from the particle collection. Titanium was produced according to equation (1) below:

$$TiCl_4(g)+2H_2(g)+T>3000^\circ\ C.\rightarrow Ti(s)+2HCl(g)$$

Ultrafine vanadium metal powder was produced using the bench scale apparatus described above. Vanadium tetrachloride liquid (B.P. 145° C.) was heated to vapor and injected in the same manner as titanium tetrachloride described above with hydrogen carrier gas. Ultrafine vanadium metal powder was produced at the rate of a 0.5 gram per hour according to one of the following equations:

$$2VCl_3(g)+3H_2(g)+T>3000^\circ\ C.\rightarrow 2V(s)+6HCl(g)$$

$$VCl_4(g)+2H_2(g)+T>3000^\circ\ C.\rightarrow V(s)+2HCl(g)$$

An ultrafine powder consisting of an alloy of titanium and vanadium was produced by two methods. Method 1 used a mixture of solid vanadium trichloride dissolved in liquid titanium tetrachloride. This mixture was then heated to vapor and injected into the plasma quench reactor in the same manner as with titanium above. In Method 2, vaporized liquid vanadium tetrachloride and vaporized liquid titanium tetrachloride were injected into the plasma quench reactor using separate injectors located in the same axial position but 180° apart on the circumference of the reactor. The chemical equations used are:

$$10TiCl_4(g)+2VCl_3(g)+23H_2(g)+T>3000^\circ\ C.\rightarrow 10Ti(s)+2V(s)+46HCl(g)$$

$$5TiCl_4(g)+VCl_4(g)+12H_2(g)+T>3000^\circ\ C.\rightarrow 5Ti(s)+V(s)+24HCl(g)$$

Ultrafine aluminum metal powder was produced by vaporizing (subliming) solid aluminum trichloride in a specially designed oven and carried into the plasma quench reactor in a stream of hydrogen gas in the manner described for titanium above. Special care was needed to insure all sections of the injection system were maintained above 200° C. to prevent formation of solid aluminum trichloride. The process utilized the following equation:

$$AlCl_3(g)+3H_2(g)+T>3000^\circ\ C.\rightarrow 2Al(s)+6HCl(g)$$

In compliance with the statute, the invention has been described in language more or less specific as to the experimental equipment and methodical features. It is to be understood, however, that the invention is not limited to the specific features described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or modifications within the proper scope of the appended claims appropriately interpreted in accordance with the doctrine of equivalents.

FIG. **8** shows a reaction chamber **20** having a virtual convergent-divergent nozzle. The chamber **20** has a plasma gas **31**, plasma arc **21**, and resulting plasma similar to FIG. **1**. Supply inlets **23** focus the incoming reactant streams **32** so as force the reactants toward the center of the reaction chamber **20**. The plasma gas **31** and reactant streams **32** as they come together produce an expansion of the reactant stream toward the outlet end of reaction chamber **23** to produce flow lines **34** with flow impedence **35**. This expansion results in rapid cooling of the reactants. Supply inlets **25** allow reactant streams **33** containing for example a reducing gas, such as hydrogen, to prevent back reactions and enhance the virtual nozzle effect and the production of the desired product.

We claim:

1. A method for thermally converting one or more metal halide reactants in a thermodynamically stable high temperature gaseous stream to a desired end product in the form of a gas or ultrafine solid particles, comprising the following steps:

introducing a metal halide reactant stream at one axial end of a reaction chamber;

introducing a reducing gas to the gaseous stream prior to or at the time the metal halide reaches a selected reaction temperature;

the reactor chamber having a predetermined length sufficient to effect heating of the gaseous stream to the selected reaction temperature at which a desired end product is available as a thermodynamically unstable reaction product at a location adjacent the outlet end of the reactor chamber;

rapidly expanding the reactant stream to rapidly cool the gaseous stream by converting thermal energy to kinetic energy as a result of adiabatic and isentropic expansion as the reaction stream expands;

adding additional reducing gas to the reactant stream after it has reacted with the initial reducing gas to minimize back reactions, thereby retaining the desired end product within the flowing gaseous stream; and

collecting the desired end product.

2. The method of claim **1**, wherein the reducing gas is hydrogen.

3. The method of claim **1**, wherein the rapid heating step is accomplished by introducing a stream of plasma arc gas to a plasma torch at the one axial end of the reactor chamber to produce a plasma within the reaction chamber which extends toward its remaining axial end.

4. The method of claim **3**, wherein the step of rapidly cooling the desired end product is accomplished by use of a restrictive convergent-divergent nozzle.

5. The method of claim **2**, wherein the desired end product is titanium metal and the reactant is titanium tetrachloride.

6. The method of claim **2**, wherein the desired end product is vanadium metal and the reactant is vanadium tetrachloride.

7. The method of claim **2**, wherein the desired end product is aluminum metal and the reactant is aluminum chloride.

8. The method of claim **2**, wherein the desired end product is a titanium-vanadium alloy and the reactants are a mixture of titanium tetrachloride and vanadium tetrachloride.

9. The method of claim **2**, wherein the desired end product is a titanium-boron composite ceramic powder and the reactants are titanium tetrachloride and boron trichloride.

10. The method of claim **2**, wherein the desired end product is uranium and the reactant is uranium hexafluoride.

11. The method of claim **4**, wherein the desired end product is uranium, the reactant is uranium hexafluoride, and the reducing gas is hydrogen.

12. The method of claim **11**, wherein the first introduction of reducing gas to the gaseous stream is prior to or at the time of the injection of the uranium hexafluoride.

13. The method of claim **12**, wherein the step of adding additional reducing gas to the reactant stream is immediately before the nozzle throat, at the nozzle throat, or immediately after the nozzle throat.

14. A method for thermal conversion of one or more metal halide reactants in a thermodynamically stable high temperature gaseous stream to a desired end product in the form of a gas or ultrafine solid particles, comprising the following steps:

introducing a stream of plasma arc gas between the electrodes of a plasma torch including at least one pair of electrodes positioned at the inlet end of an axial reactor chamber, the stream of plasma arc gas being introduced at a selected plasma gas flow while the electrodes are subjected to a selected plasma input power level to produce a plasma within the reactor chamber and extending toward its outlet end;

thoroughly mixing an incoming reactant stream into the plasma by injecting at least one metal halide reactant into the reactor chamber at or adjacent to its inlet end at a selected injection angle and at a selected reactant input rate to progressively effect heat transfer between the plasma and the resulting gaseous stream as it flows axially toward the outlet end of the reactor chamber;

introducing a reducing gas to the plasma arc gas stream prior to or at the time the metal halide reactant stream is added;

the length of the reactor chamber being sufficient to effect heating of the gaseous stream to a selected equilibrium temperature at which a desired end product is available as a thermodynamically unstable reaction product within the gaseous stream at a location adjacent to the outlet end of the reactor chamber;

directing the gaseous stream through a coaxial convergent-divergent nozzle positioned in the outlet end of the reactor chamber to rapidly cool the gaseous stream by converting thermal energy to kinetic energy as a result of adiabatic and isentropic expansion as it flows axially through the nozzle, the nozzle having a converging section and a diverging section respectively leading to and from a restrictive open throat;

adding additional reducing gas to the reactant stream immediately prior to the throat of the nozzle, at the throat of the nozzle or immediately after the throat of the nozzle to minimize back reactions and retain the desired end product in the flowing gaseous stream;

cooling the gaseous stream exiting the nozzle by reducing its velocity while removing heat energy at a rate sufficient to prevent increases in its kinetic temperature; and

separating desired end products from the gases remaining in the cooled gaseous stream.

15. The method of claim 14, further comprising the following step:

accelerating the gaseous stream rapidly into the nozzle throat while maintaining laminar flow by passage of the gaseous stream through a converging section of the nozzle having a high aspect ratio.

16. The method of claim 14, further comprising the following step:

controlling the residence time and reaction pressure of the gaseous stream in the reactor chamber by selection of the size of the restrictive open throat within the nozzle.

17. The method of claim 14, wherein the reducing gas is hydrogen.

18. The method of claim 17, wherein the desired end product is uranium and the reactant is uranium hexafluoride.

19. The method of claim 17, wherein the desired end product is titanium and the reactant is titanium hexafluoride.

20. A method for producing titanium, comprising the following steps:

decomposing a titanium compound by introducing two or more reactant streams of titanium compound and one or more other reactants into the same point in a hot plasma in a reaction chamber, such that the reactants react generally at a common point; and

rapidly expanding the reactant stream to effect cooling of the reactant stream as the reactant stream moves down the reactant chamber.

21. The method of claim 20, wherein the other reactant is hydrogen and the titanium compound is titanium tetrachloride.

22. The method of claim 21, wherein additional hydrogen is added to the reactant stream after it begins to expand to minimize back reactions and retain the desired end product in the reactant stream.

23. A method for thermally converting one or more reactants in a thermodynamically stable high temperature gaseous stream to a desired end product in the form of a gas or ultrafine solid particles, comprising the following steps:

introducing a reactant stream at one axial end of a reaction chamber;

the reactor chamber having a predetermined length sufficient to effect heating of the gaseous stream to a selected reaction temperature at which a desired end product is available as a thermodynamically unstable reaction product at a location adjacent the outlet end of the reactor chamber;

passing the gaseous stream through a virtual convergent-divergent nozzle formed by directing one or more streams of particles, droplets, liquid or gas into the main flow stream of the reaction chamber to cause the main gaseous stream to flow as if a real convergent-divergent nozzle were present, to rapidly cool the gaseous stream by converting thermal energy to kinetic energy as a result of adiabatic and isentropic expansion as the reaction stream expands; and

collecting the desired end product.

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